EXPERIENCE IN OPERATING AN EXPERIMENTAL ACID MINE DRAINAGE TREATMENT PLANT*

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In 1967, the staff of the School of Mines designed and supervised the construction of an acid mine drainage treatment plant making use of lime slurry as a neutralizing agent for a plant size study of neutralization of acid mine water. This plant was constructed to handle at least 200 gallons of water per minute containing around 500 parts per million of iron, mostly in the ferrous state, and having a pH of approximately 5 with acidity running around 1,000 parts per million on the calcium carbonate equivalent basis. A description of the plant will not be given because it was described in a recent publication.[1] At the present time, we have a range of four mines that we can use for experimental purposes. The approximate analyses of the waters from these is shown in Table 1.

TABLE 1
ANALYSES OF ACID WATERS FROM MINES 1, 2, 3, and 4

Mine No.	Field pH	Iron Total	Iron Ferrous	Aluminum	Calcium	Magaese	Acidity*	Sludge Value**	Total Solids
1	3.14	912	783	116	259	69	2400	330	7951
2	4.64	573	545	36	331	60	1022	166	6014
3	2.40	2648	1096	580			6500	510	18890
4	2.85	602	242	69			1746	236	8164

* Calcium Carbonate Equivalent
** Milliliters of sludge per liter of water tested

Extreme distances between the wells is about one mile, but no well is much more than about one-half mile from the treatment plant.

The plant, shown in Figure 1, is located on the side of a hill about 180 feet above the floor of the valley. It was orginally intended to place the plant in the valley but the movement of ground water through the low-lying level lands offered a problem in that we would not know whether our treatment was affecting a change made in the water or whether it was due to the ground water. This site on the side of a hill eliminated this problem, but it did raise a problem of raising water from the bottom of the valley to the elevation of the plant which would not exist in most acid treatment plants.

In this plant, which was manually operated, the following operations were carried out.

1) It prepared a lime slurry to be used for neutralization. This slurry was usually prepared at a concentration of one pound of lime per gallon of water. This seemed to work very well and did not require excessive amounts of slurry to be used in the treatment process.

2) It was arranged to feed the slurry into the feed water at a rate that would effect neutralization and raise it to a pH of about 10. This high pH was made necessary by the ferrous iron in the water. As our neutralization curves indicated, such iron would not come out completely until the pH water was raised to about 10.

3) The treated water was passed through an aeration plant which was designed to handle about 200 gallons of water per minute to convert the ferrous iron to ferric iron and to reduce the pH to a value acceptable by the water laws of West Virginia.

1. Holland, C. T., Corsaro, J. L., Ladish, D. J., Factors in the Design of an Acid Mine Drainage Treatment Plant, Second Symposium on Coal Mine Drainage Research, 1968, Coal Industry Advisory Committee to the Ohio Valley Water Sanitation Comm.

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4) Following this operation the water was passed through a settling basin holding about 300,000 gallons which allowed the iron, both ferrous and ferric, aluminum, as well as the calcium sulfate formed to precipitate, and the clear water to flow into the streams of the state. The ponds were large enough to accommodate the accumulation of sludge for two days to four or five days operation depending upon the concentration of iron and acid.

5) By means of a diaphragm slurry pump this sludge was pumped from the receiving basins into a sludge storage basin.

6) Here arrangements were made to decant the water from the sludge as it separated and to expose as large an area as was possible to the atmosphere to encourage evaporation. The sludge pond was also constructed with the thought in mind that some water would seep through the walls of the earth-filled basin and aid in concentrating the sludge. As it will be noted later on in the paper, this sludge disposal basin did a very good job of concentrating the sludge and removing the water at the rate at which we operated.

OPERATION

The plant treated different waters in periods. From April 1 until December 18, it operated on water from mine No. 1. The operating rate was 16 hours per day five days per week with the time from August 21 until October 4 non-operative because of a breakdown in the deep well mine pump.

From December 18, 1967 to February 19, 1968, we were in the process of laying a pipeline between the plant and mine No. 2. The operation was delayed because of the severity of the weather.

From February 19 to August 12, we operated 16 hours per day five days per week on water from mine No. 2 with the exception of a week out from April 3 to April 10, because of a failure of the deep well pump at mine No. 2.

From August 12, 1968 to September 20, 1968, we operated on water from mine No. 2, No. 3, and No. 4 mixed. Again the operating time was 16 hours per day five days per week but considerable time was lost due to sulfation preventing operations in the plant.

From September 20, 1968 to October 20, 1968, we operated on mine waters from mine No. 3 and No. 4. Again considerable time was lost during this period because of sulfation difficulties.

The flow sheet of the plant is shown in Figure 2.

OPERATING RESULTS MAKING SLURRY

Our apparatus for making slurry proved to be quite acceptable. No trouble of any kind has occurred with this apparatus other than the normal amount of attention to keeping the apparatus securely fastened to the mixing tank and items of a like nature. Only one shut-down in nearly two years of operation was occasioned by this apparatus and this was the fault of the operator.

SLURRY FEED APPARATUS

Throughout the experiments, the slurry feed apparatus consisted of some kind of a constant or very nearly constant head arrangement. The one shown in the flow diagram (Fig. 1) is typical. Considerable trouble consisted of stoppage of the valves, stoppage of the pipe, and stoppage of the pump so as to refuse to operate. Lime slurry seems to have this property, of forming solids in pipes, valves, and pumps, and it is suggested that this apparatus be installed in duplicate so that one feeder can be repaired while the other operates.

TRANSPORTATION OF TREATED ACID MINE WATER TO AERATOR AND SETTLING BASINS

This part of the plant gave us considerable trouble also. At first we had a four-inch PVC* pipe through which we forced this water after adding the lime. This pipe became clogged rather quickly and was a constant source of trouble. Then we built a one-foot square wooden flume with sufficient slope to carry this material to the aerator. This proved to be an improvement over the pipe because it could be cleaned regularly every day. However, this flume has been the source of some trouble when treating strongly mineralized water, because of deposited material in the flume.

AERATION EQUIPMENT

The aeration equipment has proved to be one of the most difficult parts of the plant to keep in operation. This was because the treated mine water contains calcium sulfate usually in supersaturated solution as well as, in our particular waters, usually a large quantity of ferrous and ferric hydroxide, and some aluminum. Some four types of air dispersal equipment were used trying to overcome this difficulty. Type 1 consisted of a special type aerator devised for treatment of metallic ores. This one did not supply sufficient aeration. The second type of air dispersal equipment used was a ceramic pad, somewhat similar to that used by chemists for aeration in laboratories but on a much larger scale. This unit gave fine dispersal of the air and worked fairly well on water from mine No. 2, which was lower in acid and iron. When applied to a mixture of water from mines No. 2, No. 3, and No. 4, however, it was a complete failure. It was almost impossible to keep the pads operating. Type 3 dispersal unit was a home-made job that was made by drilling 3/64" holes in 2" PVC pipe and arranging this at the bottom of the aerator. This worked very well for a few days but shortly stopped up when water from mine No. 2, No. 3, and No. 4 were mixed and passed through the aerator. The best results were obtained by using an air dispersion device which consisted of a PVC tube that introduced the air inside of knitted socks.** This device comes in two lengths, one some two feet long and one about eight inches long, both worked very well. In water from mine No. 2, little trouble was experienced in this type of air dispersal unit. However in water from mines No. 2, No. 3, and No. 4 mixed, and No. 3 and No. 4 mixed, arrangements had to be made to clean these socks once every day. Consequently when using them, they should be purchased in duplicate sets. In general, we are not satisfied completely with any of the air dispersion units we have used. We did not try a surface aeration unit in our settling ponds because the ponds were comparatively shallow and did not have concrete bottoms; and we thought that the mud kicked up by this device would more than off-set its advantages.

The air to this plant is supplied by two blowers developing a pressure of 1 pound per square inch and rated 300 CFM.* These blowers are placed in series so they develop 2 pounds per square inch and deliver up to 475 CFM. These aeration units have two sections and in each section are 14 air dispersion units. The results obtained from the unit as a whole are shown in Figure 3. The unit in operation is shown in Figure 4.

Operating between the flume from the treatment plant and the aerator tank is a 200 GPM* centrifugal pump working against a 10 foot head. This pump works well in low-sulfate water but when the water begins to approach the saturation point with calcium sulfate, the impellers and eye of the pump became clogged with deposited sulfate. This has proved to be very troublesome, and it seems best to advise that such a unit be installed in duplicate so that plant operations may continue while repairs are being made to one pump.

SETTLING BASINS

The settling basins (shown in Fig. 1) are about 220 feet long and have a cross section area of about 150 square feet. Even though we at times, overloaded the design by a factor of 3, they have worked well. Two ways of removal of sludge from the basin were tried, continuous operation and cyclical operation. Both proved to be possible and satisfactory, but for our particular case the alternate use of basins and pumping them out cyclically seemed to give the better results.

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*Poly Vinyl Chloride (PVC) Cubic Feet Per Minute (CFM) Gallon Per Minute (GPM)
** Made of nylon

SLUDGE PUMP AND PIPING UNIT

This unit which removed the dilute sludge from the settling basins and deposited it in the sludge storage basin worked very well indeed, as throughout the work done at the plant, little trouble has been encountered. It is necessary to have a surge tank on both the suction and discharge of this sludge pump, which was a diaphragm type pump. If these are not there, it is difficult to prevent a great deal of vibration and considerable water hammer in the lines. No trouble was experienced with sulfation* with any part of this piece of equipment.

SLUDGE DISPOSAL BASIN

This basin, shown in Figure 1, proved to be adequate and it has performed better than expected throughout the operation of the plant. Troubles experienced here consisted principally of the water decantation system becoming clogged with sludge primarily, we believe, because of the amount of calcium sulfate that was carried into the sludge basin. This again acted to clog up the pipes and prevent as efficient decantation as we would have liked to have had.

WATER QUALITY OBTAINED

In Table II and III, we have presented analyses of the raw water fed to the plant and of the treated water flowing from the plant. It will be noted, we have presented two values for the water fed to the plant.

1) The average value of all the water fed.
2) An approximate one-week run showing the variation and results achieved during one representative week. In the overflow, we have presented the analyses for the treated water during the one-week sample run.

It will be noted, in the case of waters treated from mine No. 1 and No. 2, that results have been quite good and that we have, in general, kept the iron in the overflow water less than 5 parts per million, and in some cases even less than 1 part per million. This is only accomplished, however, by raising the pH to a value lying between 9.5 to 10.5 depending on the water. In the mixed waters from mines No. 3 and No. 4, and No. 2, No. 3, and No. 4 due to difficulties from sulfation and some trouble with the slurry feed apparatus, we were not able to maintain the pH at the value we would have liked to have had. It will be noted in these cases the iron in the effluent water has been quite high, although in the case of the mixture from mines No. 3 and No. 4, we have been able to keep it fairly close to the state limits. In the effluent water from mines No. 2, No. 3, and No. 4, we have not been able to do this quite so well. This is because we had not learned to cope quite so well with the effects of sulfation.

When the water was treated all of the water discharged was comparatively high in calcium which means that the water will be a hard water. In mine No. 2, the water discharged contains more total solids than did the water entering the plant. In the case of mines No. 1, and the mixture from mines No. 2, No. 3, and No. 4, and from mines No. 3 and No. 4, we have been able to appreciably lower the total solids in the water. Such total solids are not included in the standards of the state so this, at present, is not really a serious difficulty.

Not much tasting of the water fed to the plant was done by anyone, but it can be said, in general, the taste of the water, to put it mildly, was unsatisfactory. The treatment process greatly improved the taste, although even with the treatment which we have in this plant, the taste of the effluent water is not particularly desirable.

These results indicate that with high acid waters, treatment is going to be more difficult than with more amendable water and sulfation is going to pose some real serious problems.

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* Deposits of calcium sulfate mixed with iron hydroxide from the treated water

Table II
Operating Results of the
Acid Mine Drainage Treatment Plant
Water Quality

Feed Water

pH Lab	pH Field	Total Iron	Ferrous Iron	Aluminum	Calcium	Magnesium	Acidity	Sludge Volume	Solids Total	Solids Susp.
					Mine No. 1					
					Average of Complete Test					
3.14	3.63	912	783	116	259	69	2400	330	7951	
					Week Sample					
3.45	3.6	882	762	137			2160	280	7838	
3.35	3.55	900	787	144			2080	420	7937	
3.25	3.	870	782	98	312	22	2120	300	7715	
3.4	3.50	877	778	116			2060	340	8005	
3.2	3.3	346	391	151			2090	290	7522	
3.30	3.45	907	760	NLA	276	138	2110	380	7753	
					Mine No. 2					
					Average of Complete Test					
4.64	5.43	573	545	36	331	60	1022	166	6014	
					Week Sample					
5.00	6.00	578	546	35			1000	130	4858	
5.60	5.8	594	550	13			995	100	4780	
4.58	5.35	574	542	39			960	130	4930	
4.92	6.0	570	530	42			990	160	4890	
					Mines Nos. 2, 3, & 4					
					Average of Complete Test					
2.64	2.78	1372	831	270	110	37	3706	1398	10400	
					Week Sample					
2.52	3	1964	982	414			2790	536	13954	
2.53	3	1443	773	250			2278	464	10453	
2.55	3	1470	973	295	152	46	2155	270	10532	
2.59	2.9	1475	979	216			2109	456	9848	
2.72	3.25	1065	563	179			3027	272	9410	
					Mines 3 & 4					
					Average of Complete Test					
2.55	2.00	1925	1147	434	161	33.8	6473	490	15138	
					Week Sample					
2.53	2+	2040	1309	444			7406	546	16201	
2.61	2+	1572	908	333			5381	396	13539	
2.61	2+	1973	1282	475			7180	472	14582	
2.52	2+	1964	1198	450			7242	506	16164	
2.55	2+	1931	1248	452			7168	512	14182	
2.56	2+	1897	1206	435			7076	476	14996	
2.53	2-	1862	1025	456	165	46	7172	472	15427	
2.54	2+	1979	1301	451	174	4	7343	406	15372	

Table III
Operating Results of the
Acid Mine Drainage Treatment Plant
Water Quality

Treated Water

pH		Total	Ferrous	Alum-		Magnes-		Sludge	Solids	
Lab	Field	Iron	Iron	inum	Calcium	ium	Acidity	Volume	Total	Susp.
					Mine No. 1 Week Sample					
9.80	10.7	5	Nil	35	576	83			4265	772
9.50	10.05	5	Nil	15					4000	607
9.90	10.85	2	Nil	17	504	70			3970	485
9.4	10.05	3	Nil	12					4450	101.5
10.5	11	5	Nil	8					3741	585
					Mine No. 2 Week Sample					
8.00	7.95	2	Nil	20	760	83			4193	150
8.68	9.0	4	Nil	19					4278	140
8.50	8.0	1	Nil	20					4360	180
8.22	8.5	3	Nil	26					4292	141
8.05	7.75	2	Nil	26	744	112			4587	88
6.30	6.65	20	Nil	22					4400	132
6.70	7.6	6	Nil	23					4253	60
					Mines 1, 2, & 3 Week Sample					
7.93	7.9	13.7	Nil	.82					4107	392
7.99	7.5	10.8	Nil	.83	692	135			4372	237
5.51	6.85	19.9	5.3	1.06					5059	3502
10.01	9.9	16.1	Nil	.51	746	99			13,921	1827
7.81		4.7	Nil	.68					4460	879
					Mines 3 & 4 Week Sample					
11.15	11+	Nil	Nil	7.4					5764	119
8.41	7-	35.1	21.5	3.02	972	111			5935	1753
11.13	9+	5.8	Nil	20.1	912	113			5087	737
10.28	7+	1.3	Nil	36					5898	296
8.29	6+	4.7	Nil	25.4	854	24			5368	1988
10.28	11	3.6	Nil	15.9	690	34			5419	155

HARDNESS

It will be observed in Table III, that the hardness of the treated water from mine No. 2 is quite high. As an experiment, it was decided to treat this water with sodium carbonate to reduce this hardness to some acceptable value. Consequently, a plant was designed that would treat 10 gallons of water per minute and feed the sodium carbonate in the required amounts automatically. The plant is shown in Figure 5. Both the inflow water and the sodium carbonate are arranged to operate under a constant head, through a fixed orifice. The results of this experiment are shown in Table IV. It will be noted that the calcium hardness was well taken care of by the sodium carbonate. The sodium carbonate method of neutralizing hardness, however, has some serious disadvantages. One is with high concentrations of calcium sulfate in the water to be removed by the sodium carbonate as in this case, it leaves the water with a strong saline taste. This would be more undesirable than would the hardness. The cost of the sodium carbonate to correct this hardness is 41 cents per thousand gallons of water treated. The total cost of the treatment, including cost of plant, labor, electricity, etc., for correction of hardness would easily run twice this amount. A final disadvantage is it discharges the water at too high a pH to conform to the water laws of West Virginia.

Table IV
Results of Treating Water From Mine 2
From Treatment Plant With Sodium Carbonate
To Reduce Hardness

pH Lab	pH Field	Total Iron	Ferrous Iron	Aluminum	Calcium	Magnesium	Solids Total	Solids Susp.
			Feed Water From Acid Treatment Plant					
7.32	7.5	4	Nil	8			4616	26
8.10	8.5	2	Nil	20			4446	20
8.49		1	Nil	10	320	97	2814	315
7.70	8.4	1	Nil	15			4265	40
7.35	7.6	1	Nil	7			4336	65
			Overflow Water From Hardness Treatment Plant					
8.00	8.15	1	Nil		24	49	3870	170
9.30	9.3	1	Nil		Nil	50	4112	12
9.95	9.6	1	Nil		Nil	58	4480	121
10.20	9.85	1	Nil		Nil	52	4750	115
10.22	10.15	1	Nil		Nil	58	4886	83
10.15	10.85	2	Nil		Nil	58	4737	70
9.80	10.4	1	Nil		Nil	58	4374	58
8.30	8.65	2	Nil		80	117	3980	

SLUDGE FORMED

The cost of disposing of the sludge when treating acid mine drainage has always been a bug-a-boo. The results of our experimentation insofar as formation of sludge is concerned is shown in Table V. It will be noted in this table, that insofar as the formation of sludge is concerned, large quantities are formed in the settling basin. It will also be noted that even by as simple a process as letting it evaporate and decant the clear water from the sludge storing basin, a very good job has been done of reducing the large volume of sludge to a rather small one.

It will be noted that insofar as total volume of water treated is concerned that as of October 20, 1968, only 2 per cent of it remained in the storage basin as sludge; and of the sludge estimated to have been deposited in the settling basin that only 7 per cent remains in the storage basin.

In connection with this though, it should be remembered that our plant has not been continuously operated, in that it is operated only five days per week and 16 hours per day; and there have been periods that it did not operate at all during the nearly two years the study has been going along. Our best estimate of the capacity of this sludge basin to concentrate sludge is, that if we had operated 24 hours a day, 365 days a year, we could have handled about 200,000 gallons per 24 hour day of water containing around 2500 parts per million acid, and 900 parts per million iron. With this type of feed water, the sludge remaining in the pond at the end of the year, we estimate, would not be more than 3 per cent of the water pumped.

When treating water such as existed in mine No. 2, we could have handled possibly three times this much water, but had we been treating water such as that water from mines No. 3 and No. 4 when mixed, the amount of water treated would probably have to be reduced by one third.

TABLE V
OPERATING DATA PERTAINING TO SLUDGE
OPERATING DATA

Period	Water Treated		Estimated Volume of Sludge Pumped from Settling Basins	Sludge Remaining in Sludge Storage			Total Sludge in Pond as Overall Percentage	
	Average Total Acidity	Gallons Pumped		Gals.	Percent of Sludge Pumped	Percent of Water Treated	Sludge Pumped	Water Pumped
Apr. 1 to Dec. 18, '67	2399	21,801,000	7,200,000	596,000	8.3	2.7	8.3	2.7
Feb. 19 '68 to Aug. 12 '68	1022	11,628,000	1,850,000	24,000	1.3	.12	6.4	1.9
Aug. 12 '68 to Sept. 20 '68	3707	3,160,000	1,140,000	20,000	1.8	0.6	6.9	1.7
Sept. 20 '68 to Oct. 20 '68	6473	2,319,000	1,140,000	191,000	16.6	8.3	7.0	2.0

TABLE VI
SLUDGE ANALYSIS AT VARIOUS DATES

Date	Percentages of Total Iron	Ferrous Iron	Aluminum	Calcium	Magnesium	Carbonate	Sulfate	Water of Hydration	Insoluable	Spec. Gravity	Total Solids
6- 6-67	23.1		2.3	15.5	19.4					1.34	14.3
9-19-67	14.7		1.7	10.4	2.1				2.8	1.37	20.3
10- 2-67	19.0		1.8	12.2	2.7				.5	1.22	16.8
2- 6-68	27.4	Nil	7.7	12.1	.2	3.9	29.4	19.6	.5	1.10	13.9
7-25-68	28.3	Nil	8.5	12.9	3.8	2.1	27.1	17.7	.2	1.09	20.5
11-13-68	26.9	Nil	8.0	9.9	.4	6.1	30.3	18.6	.6	1.09	11.1

LIME REQUIRED

Careful records were kept of the lime required as we went along with our program. These records were compared with the weights of lime, and the theoretical amount of lime required to neutralize the acid. The agreements are close in all cases. It will be noted by consulting Table VII that the amount of lime required to treat water in thousand gallon units and per part per million of acid in the water vary somewhat. This is due to several causes. (1) In the case of the water treated from mine No. 2, No. 3, and No. 4 a slight insufficiency in lime existed. This same is also true to a lesser extent in the case of the mixed water from mines No. 3 and No. 4. Other factors that entered were the (2) presence of bicarbonates and (3) dissolved CO_2.

TABLE VII

LIME REQUIRED FOR TREATING WATER AND COST AT $24/TON

Period	Water Treated In 1000 Gal. Units Treated	Lbs. of Lime Used Per 1000 Gal.	Lbs. of Lime/ 1000 Gal. Per Part Per Million of Acid in Water	Cost of Lime in Cents per 1000 Gals. per part per Million of Acid With Lime at $24 per ton
Apr.1-Dec.18,1967	21800	14.8	.0063	.0076
Feb.19-Aug.12,1968	11628	8.4	.0081	.0098
Aug.12-Sept.10,1968	3160	19.7	.0053	.0064
Sept.12-Oct.16,1968	2319	40.7	.0063	.0076
		Average	.0065	.008

ECONOMICS

Operating this plant has given us some insight into the economics of acid mine drainage treatment by lime neutralization.Three questions here are paramount; namely, what will it cost and how much and what kind of land will be required on which to build a plant.

Costs of treatment are difficult to estimate. This is true because the cost of lime varies with the location of the treatment plant with respect to the nearest lime producer. Also, costs of labor vary from one section to another. The costs of construction also vary with location and type of excavation required. Also, as shown in Table VII, some differences exist among mine waters in the amount of lime required for neutralization. So the costs given are based on our experience, and here the cost of the land for the plant was low. We allowed about $200 per acre and we had no hard rock excavation to do. Therefore our figures cannot be blindly applied, but we believe they give us some indication of costs. Our estimates for the cost of treating acid mine water are shown in Table VIII. It will be noted that the cost will be substantial, and it increases as the acidity of the water increases.

Our experience indicates that the sludge production will not be as large as at first feared; but it is still substantial. If it has to be stored in surface disposal units, then in a few years considerable areas of surface, in mine areas affected by acid mine drainage, are going to be covered by sludge.

Also, it will be noted that where strongly acid water or if large quantities of acid water of less strength are to be treated, substantial areas for plant construction and sludge disposal will be required. In some areas of the coal fields, land of the nature required and acreage are scarce.

The lesson seems to be plain that the treatment of acid mine wastes will not be easily and economically achieved by lime neutralization, nor in most cases, will the problems associated with the sludge disposal be easily handled.

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TABLE VIII

ESTIMATED COSTS OF LIME NEUTRALIZATION OF ACID MINE DRAINAGE
ALL COSTS IN CENTS/1000 GALLONS

Plant Capacity Gallons/ Day	Approximate Acidity Concentration	Approximate Iron Content	Plant Cost (Except Sludge Removal)	Lime**	Labor	Sludge Disposal	Mainten- ance	Contin- gencies	Total	Sludge Accumulation Acre-Ft./Yr.
300,000	6500	2000	12.0	53	14.0	11.0	6.0	5.0	101	13
900,000	6500	2000	11.2	51	12.6	10.5	5.8	5.0	96	39
2,700,000	6500	2000	10.4	49	11.8	10.5*	5.5	5.0	92	117
8,100,000	6500	2000	9.8	48	11.0	10.5*	5.3	5.0	89	351
300,000	3400	1000	9.5	28.0	10.0	8.0	4.0	3.0	62.5	9.8
900,000	3400	1000	8.5	26.0	5.0	7.0	3.0	3.0	52.5	30.1
2,700,000	3400	1000	7.5	25.5	2.5	7.75*	2.5	3.0	48.5	91.0
8,100,000	3400	1000	7.25	25.5	2.0	7.50*	2.5	3.0	47.75	273.0
300,000	1400	650	9.5	12.9	8.0	4.0	3.0	3.0	34.8	4.9
900,000	1400	650	8.5	11.5	4.0	3.5	2.5	3.0	33.0	15.4
2,700,000	1400	650	7.75	11.0	2.0	3.75*	2.0	3.0	29.5	45.4
8,100,000	1400	650	7.25	11.0	1.6	3.75*	2.0	3.0	28.6	136.5
300,000	650	325	8.5	6.1	6.0	2.0	2.5	2.5	27.60	2.8
900,000	650	325	7.5	5.7	3.0	1.8	2.0	2.5	22.50	7.7
2,700,000	650	325	6.75	5.5	1.8	1.9*	1.5	2.5	19.95	23.1
8,100,000	650	325	6.5	5.5	1.0	1.9*	1.5	2.5	18.90	68.6

*These costs allow for excavating some hard rock.
**Cost of hydrated lime taken at $24.00/ton bagged, $22.00/ton bulk.

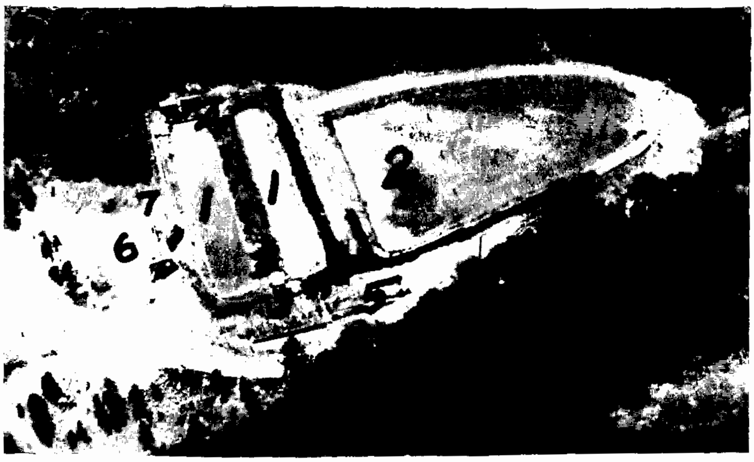


FIGURE 1
AERIAL PHOTOGRAPH OF THE ACID MINE DRAINAGE TREATMENT PLANT
(1) Settling basins, left one is full of treated water.
(2) Sludge disposal basin. (3) Sludge pump house. (4) Aeration plant. (5) Water softening plant. (6) Acid treatment house
(7) Flume to aeration plant.

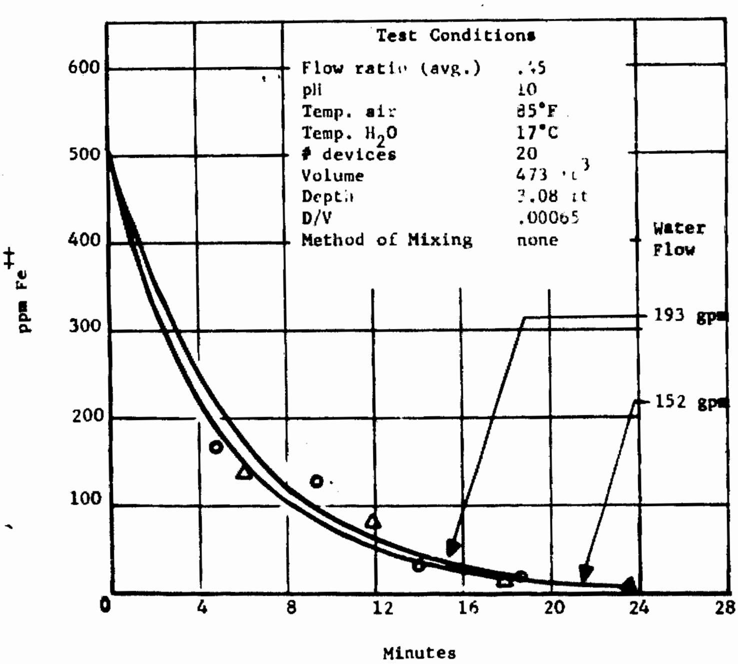
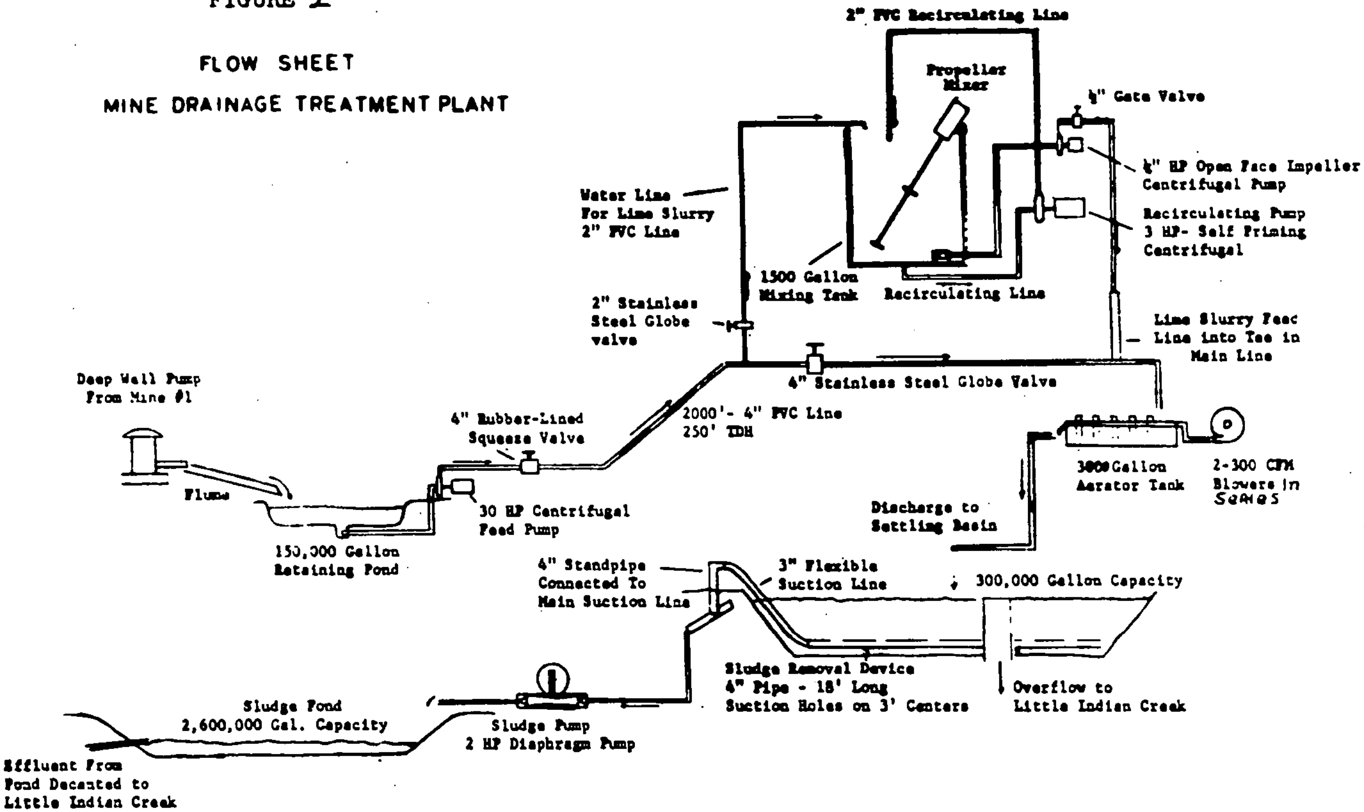


FIGURE 3
CURVES SHOWING AERATION RESULTS ACHIEVED
Note the abscissa description refers to the minutes the treated water has been in the aerator. The PPM on the ordinate refers to the parts per million of ferrous iron remaining in the treated water.

FIGURE 2

FLOW SHEET

MINE DRAINAGE TREATMENT PLANT



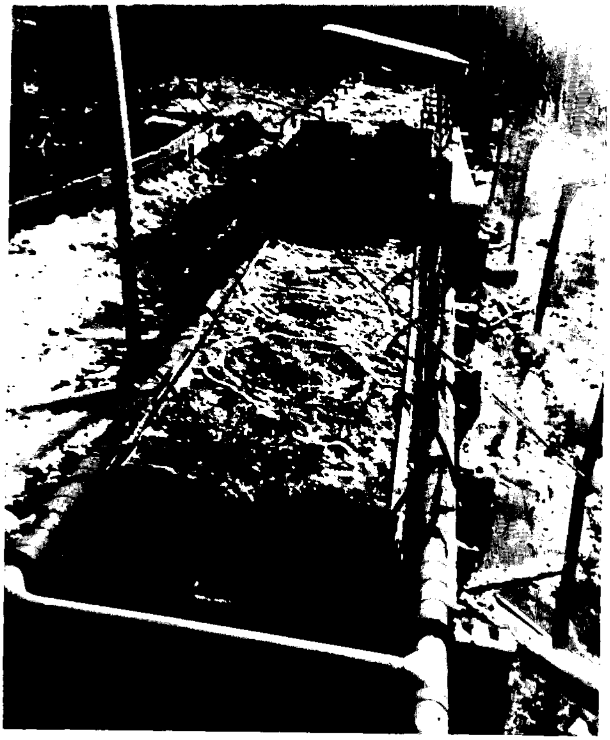


FIGURE 4
AERATION UNIT IN OPERATION

FIGURE 5
PHOTOGRAPH OF WATER HARDNESS TREATMENT PLANT
(1) Treated water. (2) Sodum Carbonate solution metering arrangement. (3) Water metering device and discharge of treated water. The overflow is through a pipe not visible in the lower foreground.